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A DEVICE FOR MEASURING GULLY HEADWALL MORPHOLOGY

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ABSTRACT

This paper describes a low-cost device for measuring the three-dimensional morphology of a gully headwall. The device was designed to operate in a gully system with the following characteristics: overhanging banks caused by a thick, dense root mat; retreat of the underlying unconsolidated sediments through small slab failures, leading to a considerable variation in retreat rate at each point on the headwall; and changes in the orientation of the headwall owing to changes in sediment properties and the topographical and hydrological controls of gully growth. The device is used to measure a series of closely spaced vertical profiles of the headwall, and the collected data are combined to draw a contour map showing the distance from the plane of the instrument to the headwall. Comparing maps for sequential times enables retreat rates for the diffferent proportions of the headwall to be quantified.

KEY WORDS gully erosion; profiling device; headwall retreat; bank retreat; root mat

INTRODUCTION

Gullies have been identified in many regions. Active gully systems commonly develop in unconsolidated materials, and often result from changing patterns of land use and associated changes in catchment hydrology (Bocco, 1991; Oostwoud Wijdenes and Bryan, 1991). Monitoring gully development has provided important information on the processes, rates and geomorphological controls of gully initiation and growth (Campbell, 1989; Graf, 1988). The form and rate of change of gullies are normally measured by repeated surveys of headcut locations, cross-sections and longitudinal profiles (e.g. Seginer, 1966; Harvey, 1974; Oostwoud Wijdenes and Bryan, 1991). Typically, this can be achieved using standard surveying equipment such as an engineer's level and stadia rod. Other equipment, such as erosion pins installed horizontally into the gully sides, may be used to monitor small-scale changes in form, particularly where these changes occur relatively slowly (e.g. Harvey, 1974; Crouch, 1990).

The three-dimensional (3D) profiler presented in this paper is a development of the bank profilers described by Hudson (1982), Pizzuto and Meckelnburg (1989) and Lawler (1993), which are used to measure river bank profiles along overhanging sections. The 3D profiler was designed to monitor the changes in headwall morphology in active gullies which have developed because of changes in land use in an urban area in Saskatchewan, Canada. The dynamics of headwall retreat in gullies vary with site conditions. In this specific case the presence of a thick, dense root mat has resulted in the formation of a well-developed overhang. Because the timing and mechanism of retreat is different for the root mat and the underlying sediments, an understanding of gully growth requires data for both types of headwall materials. Headwall retreat in the unconsolidated sediments occurs through the failure of blocks or slabs of sediment. The size of the slabs is variable, but typically much less than the headwall area. As a result, single or even several headwall profiles may not provide a realistic estimate of headwall retreat, depending on whether or not the profiles coincide

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with the slab failures. Furthermore, to reliably measure headwall retreat rates the plane of a profile should be perpendicular to the direction of retreat. In a gully, however, the direction of headwall retreat may vary around an average direction in an apparently random manner, depending on local conditions, and as a result a single or even several profiles may prove to be inadequate for describing gully growth. To overcome these problems, a low-cost 3D profiler was designed which, in its current configuration, measures up to 21 vertical profiles spaced 25 cm apart over a headwall width of 4 m. Anecdotal evidence indicated annual rates of headwall retreat of tens of centimetres in the gullies of interest. The 3D profiler was designed to measure gully headwall morphology with an accuracy of 2·5 cm and repeat measurements have shown that this accuracy is attainable in the field.

CONSTRUCTION

The profile device consists of three main components: a horizontal board which spans the gully, a vertical post and a distance rod (Figure 1). It is constructed so that measurements are taken over a 25 × 25 cm grid. The horizontal board is constructed from nominal 5 × 20 cm lumber with a strengthening rib of nominal 5 × 10 cm lumber screwed to the upper surface. The length of these boards depends on the width of the gully; 5 m was convenient in this instance. Brackets made from 3 mm angle-iron are fastened along the front edge of the board at intervals of 25 cm. These brackets provide rigid support for the vertical post at convenient intervals across the gully. A builders' level is mounted on the board so that the device can be levelled in the field. Holes are drilled at each end of the horizontal board to allow it to be secured to the ground with iron rods once it has been correctly positioned. During measurement there appeared to be no sag in the horizontal board. Even so, any sag would have a negligible effect on the position of the vertical post. For wider gullies, where sagging of the horizontal board could be a concern, the horizontal board could be replaced by an aluminium structure or a central, fixed support post could be used.

The vertical post is constructed from 5 × 5 cm square iron tubing. Again, length is determined by the depth of the gully; in this study the post was 5 m long. Angle brackets constructed from 2 mm aluminium were riveted 25 cm apart along the length of the post. By extending these brackets a short distance (4 cm) to the front and rear of the vertical post, the headwall and sidewall profiles can be measured. The post was secured to a square base (15 × 15 cm) through which an 8 cm long spike protruded. The base prevented the post from sinking into the substrate, and the spike steadied the post once it was correctly positioned. A rest extending 30 cm in front of the post was used to hold the distance rod perpendicular to the post. The rest was formed from 6 mm × 50 mm flat aluminium stock, and was riveted at the requisite distance from the post. The post was fitted with a bi-directional level to ensure that it was vertical, and a rope and elastic strap to hold it firmly in the brackets on the horizontal board. The rope and elastic strap can be released from the gully floor by the instrument operator and are sufficient to keep the vertical post in position during measurements. A tape measure was riveted to the back of the post so that the position of the distance rod could be readily determined.

The distance rod consisted of a collapsible stadia rod and was used to measure the distance of the headwall from the vertical post. A builders' level fitted to the stadia rod enables it to be held in a horizontal position during measurement. Even though, for this project, a 25 × 25 cm sampling grid was used, by installing additional brackets on the horizontal board and the vertical post, the sampling density could be varied to obtain measurements in headwall areas of particular interest.

OPERATION

The profile device provides accurate measurements so long as it is securely positioned and the components are held in their proper orthogonal position (Figure 2). First, the horizontal board is positioned at an appropriate distance from the headwall, levelled, and secured by the metal rods. For repeat surveys the metal rods should be installed permanently, for example in poured concrete or by inserting the rods into the subsoil to depths below the annual depth of freezing. Furthermore, as insurance against the possibility of the rods being lost during a catastrophic erosional event, the position of the rods and horizontal board should be surveyed with respect to fixed reference points. The vertical post is positioned in the bracket that holds it

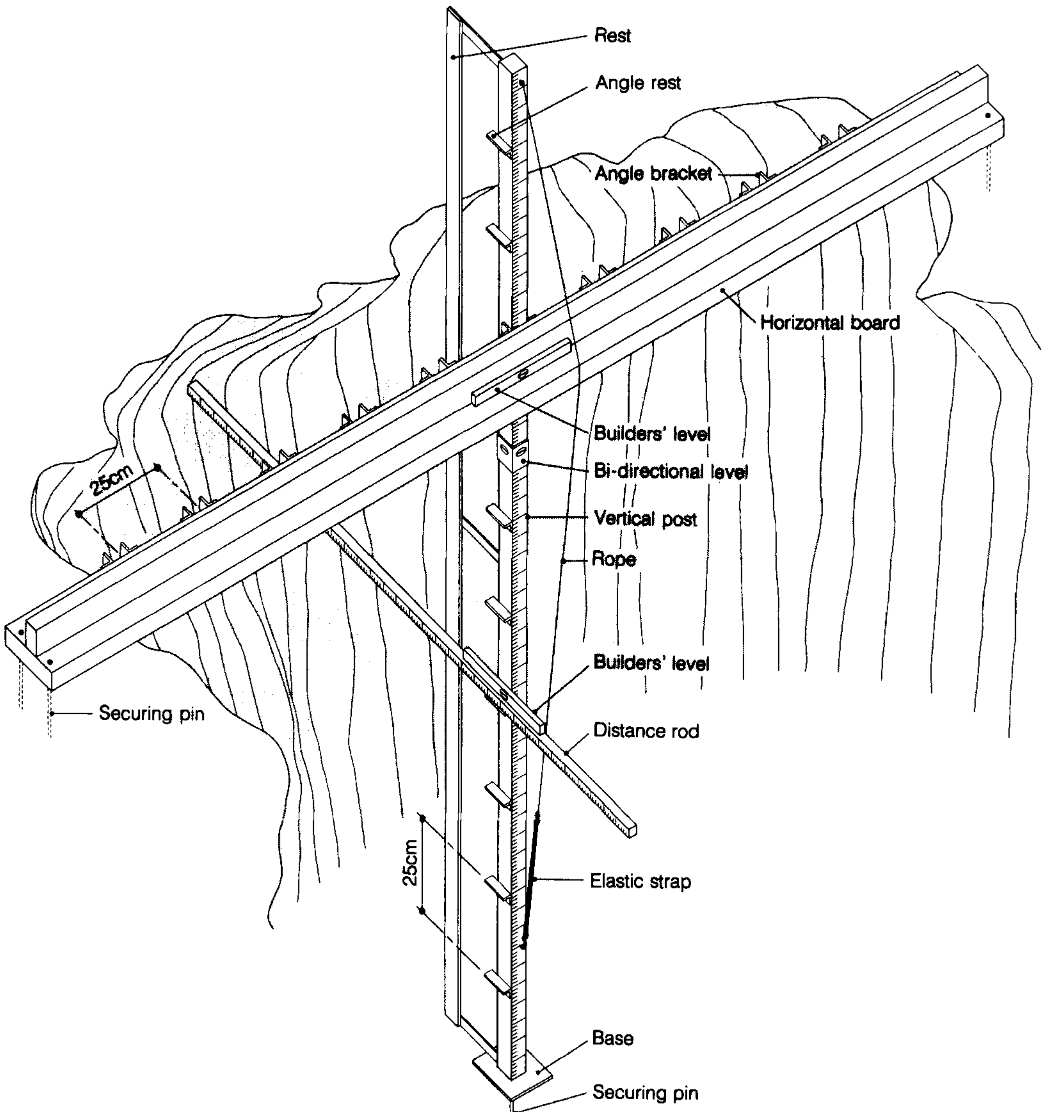

Figure 1. Sketch showing the design of the 3D profiler

closest to one edge of the gully, trued up, and secured by the strap. Finally, the distance rod is placed on each angle bracket and the distances to the headwall and sidewall recorded. The thin distance rod is especially useful for probing any obstructive root mat that may be present. After each set of measurements is completed, the vertical post is repositioned and the process repeated. A cross-sectional profile of the gully can also be taken by measuring the sidewall distances from the two extreme post positions. This requires a 90° rotation of the post to align the distance rod parallel to the horizontal board spanning the gully. In addition, in its uppermost position the distance rod may be used as a reference level for accurately measuring the morphology of the upper edge of the headwall.

RESULTS

With standard graphics software packages the data are readily plotted as a contour map, together with the cross-sectional profile of the gully (Figure 3), which results in a record of gully headwall morphology at a

Figure 2. Typical field set-up of the 3D profiler

particular time. Comparing a series of such figures will produce a record of rates of recession and changes of form which provides valuable insight into the geomorphological processes involved in gully formation. The 3D profiler facilitates such detailed microscale morphological studies, particularly where overhangs and obstructive root mats preclude the use of standard survey methods.

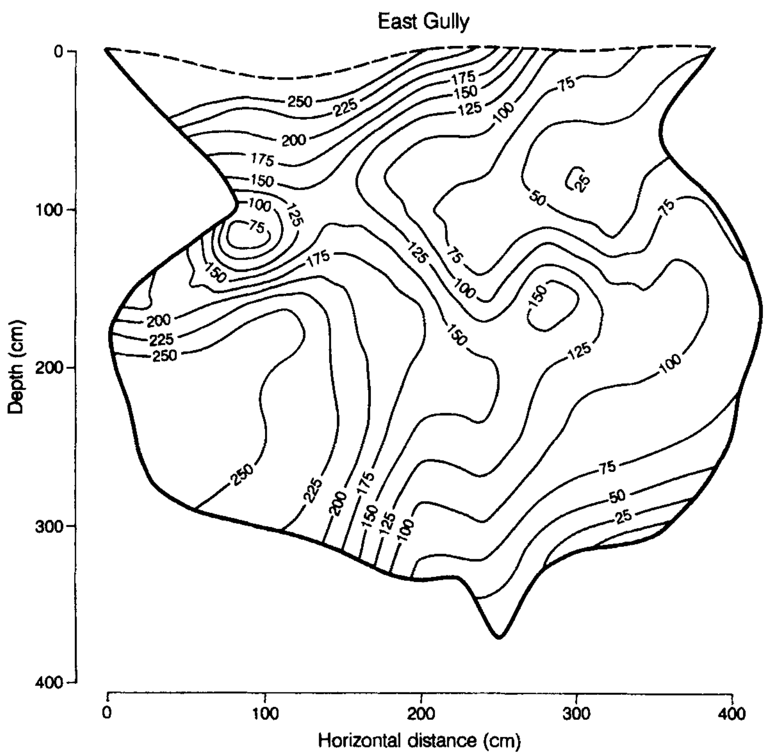

Figure 3. Sample of the output of the 3D profiler, showing gully headwall morphology. Contour line labels indicate distance (in cm) from instrument plane to headwall

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